Capacity Allocation in Vertically Integrated Rail Systems:
A Sequential Bargaining Game Approach with Focus on the US Context

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Outline

- Background
- The model
  - Modeling framework
  - Pre-negotiation
  - Bargaining game with complete information
  - Bargaining game with incomplete information
- Numerical analysis
- Concluding remarks

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Background

- Passenger rail resurgence in the US
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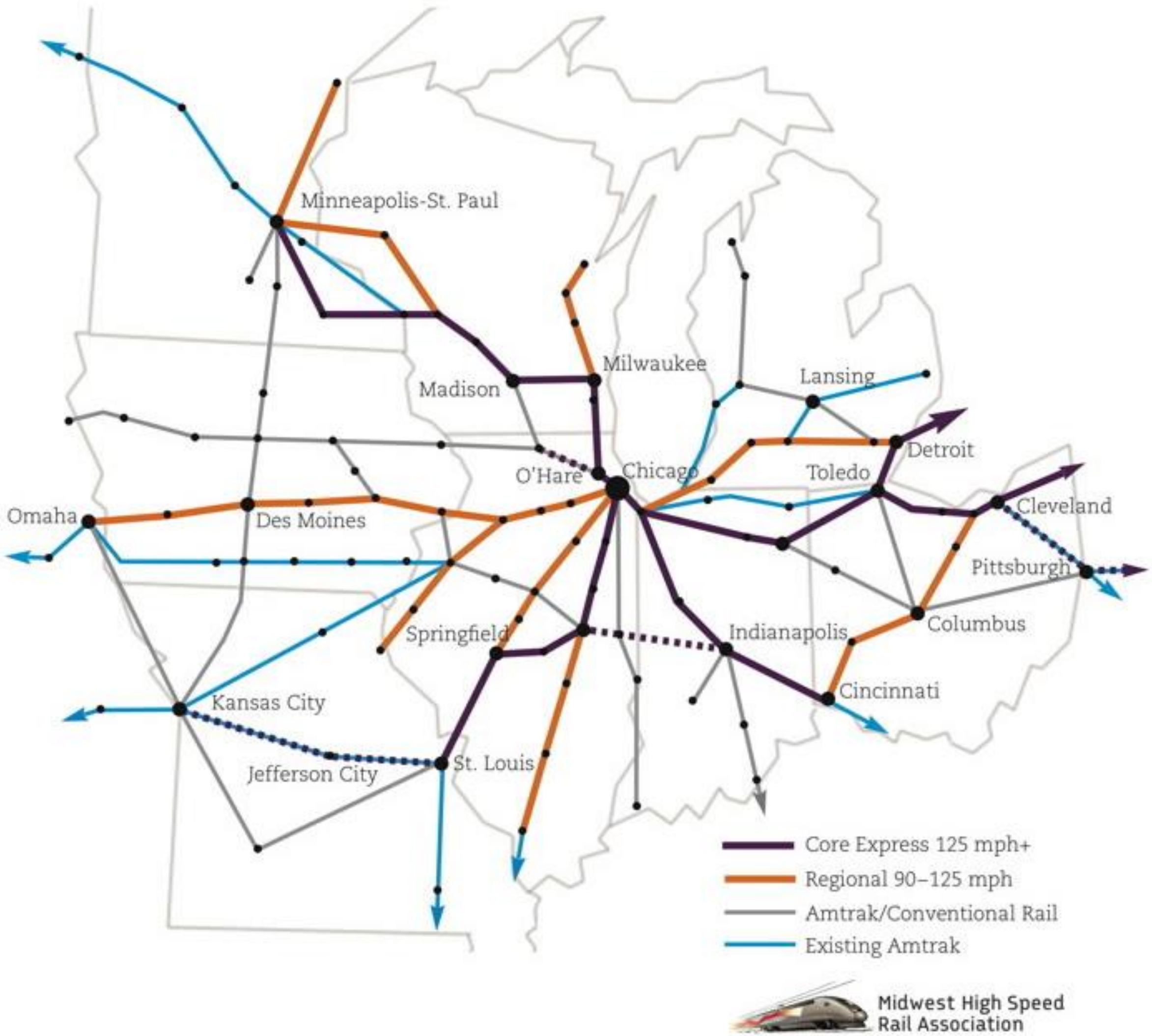
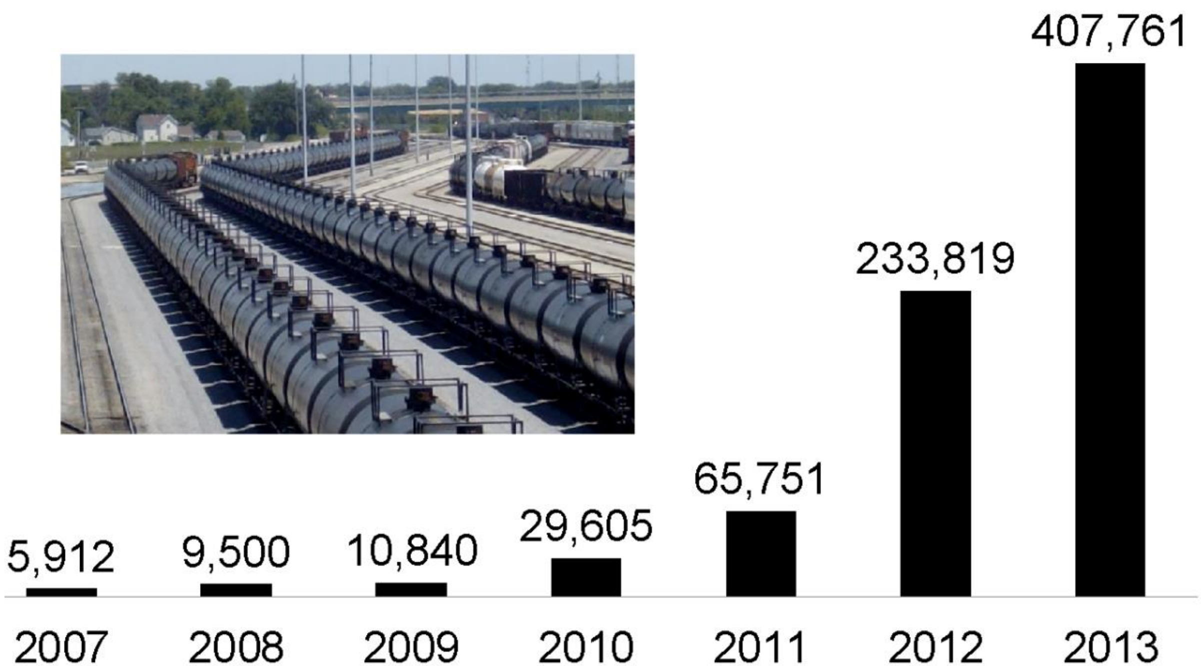


Background

- 15% increase in Class I Railroads' revenue ton-miles between 2001 and 2011
- About 6800% increase in originated carloads of crude oil on Class I Railroads



Background

- Challenges of Higher Speed Rail lines
  - Single tracks with siding (meets and overpasses)
  - S (negative impacts
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It is important to develop a capacity allocation mechanism taking into consideration different characteristics of the US railway market

Background

- Issues to be considered in allocating rail capacity in the US:
  - Complementary feature of rail tracks
  - Capacity is endogenous
  - Amtrak's priority (Public Law 110-432)
  - Temporal variations in passenger demand
  - Train schedule inconvenience to passengers
  - Freight railroads keep their operating and financial information confidential

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Background

- Capacity allocation mechanisms:
  - Administrated mechanisms

Appropriate for rail networks fully owned and controlled by governments

  - Value based mechanisms { Value based / Yield management / Value of service

Do not provide incentive for train operators to seek a more efficient use of capacity

  - Market-based mechanisms

Neglect congestion impacts and scarcity of capacity, both prominent in the U.S. rail sector

Apply to open access markets, which do not exist in the U.S

Possession of private information is not incorporated into the above the capacity allocation mechanisms

The first sequential bargaining approach to capacity allocation in US rail system

Efficient and effective schemes for capacity allocation in the U.S. rail industry must account for its specific characteristics

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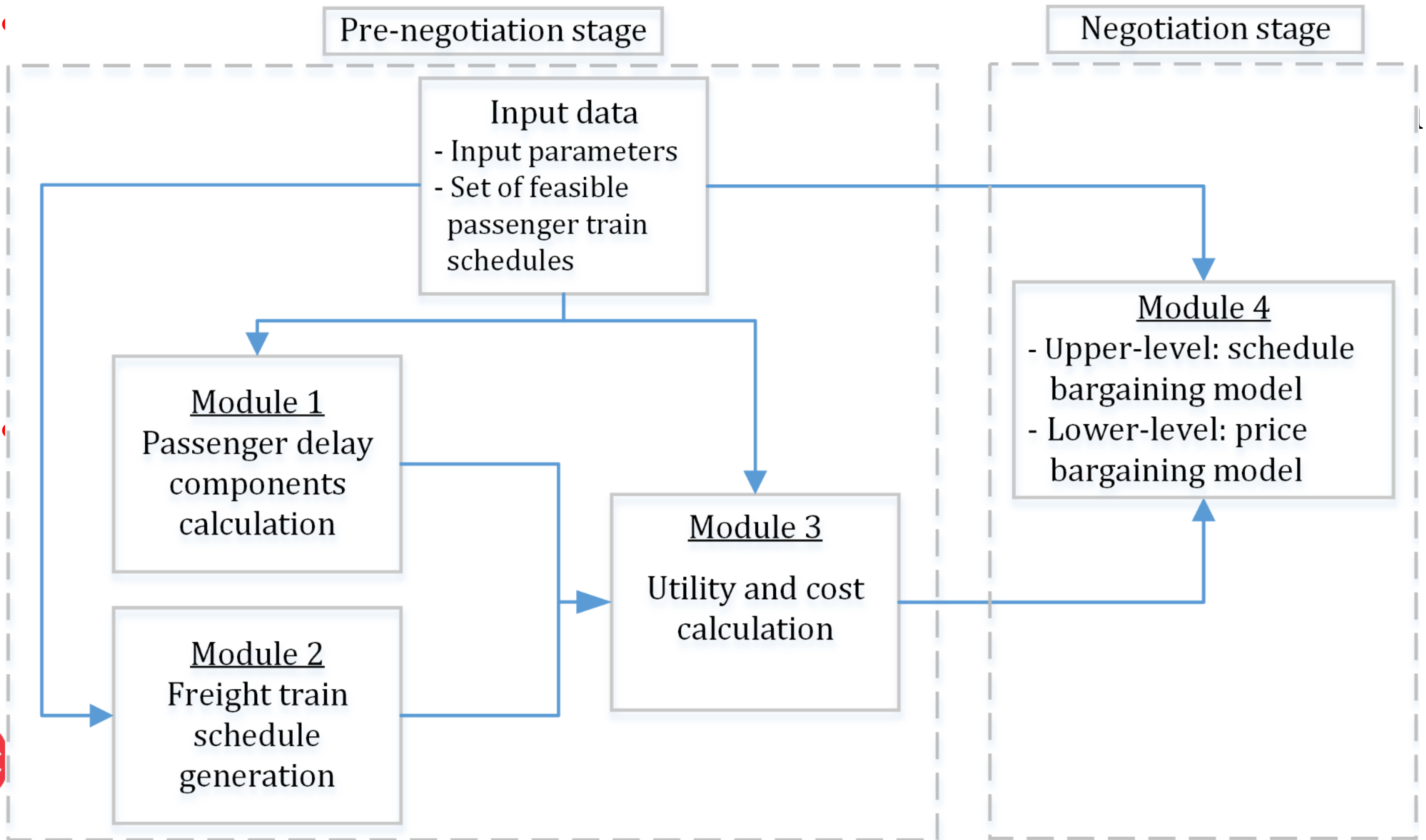
The model

Modelling Framework



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The model

Module 1: Computing passenger delay components

- A set of feasible passenger train schedules is given (*FPTS*)
- Constant fare
- An initial schedule (baseline schedule) and associated travel demand are given
- Delay components:
  - Schedule delay
  - En-route delay

The model

Module 1: Computing passenger delay components

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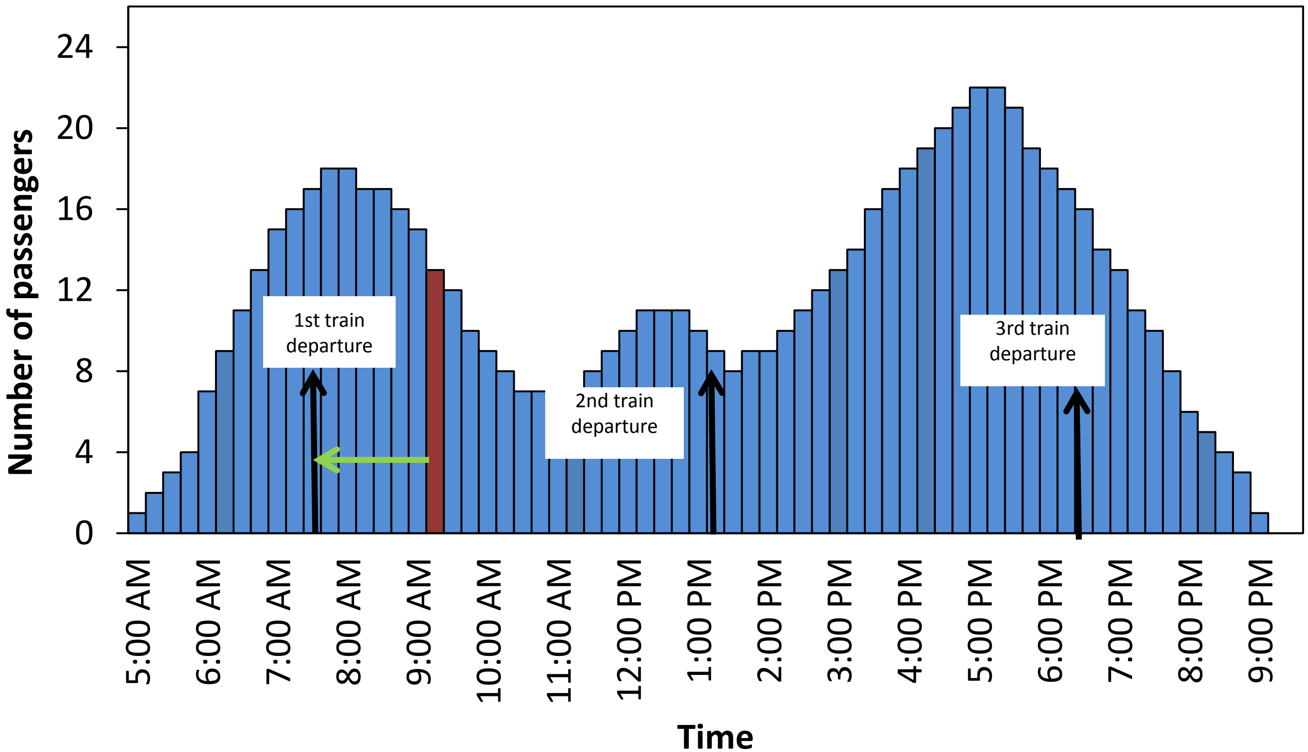
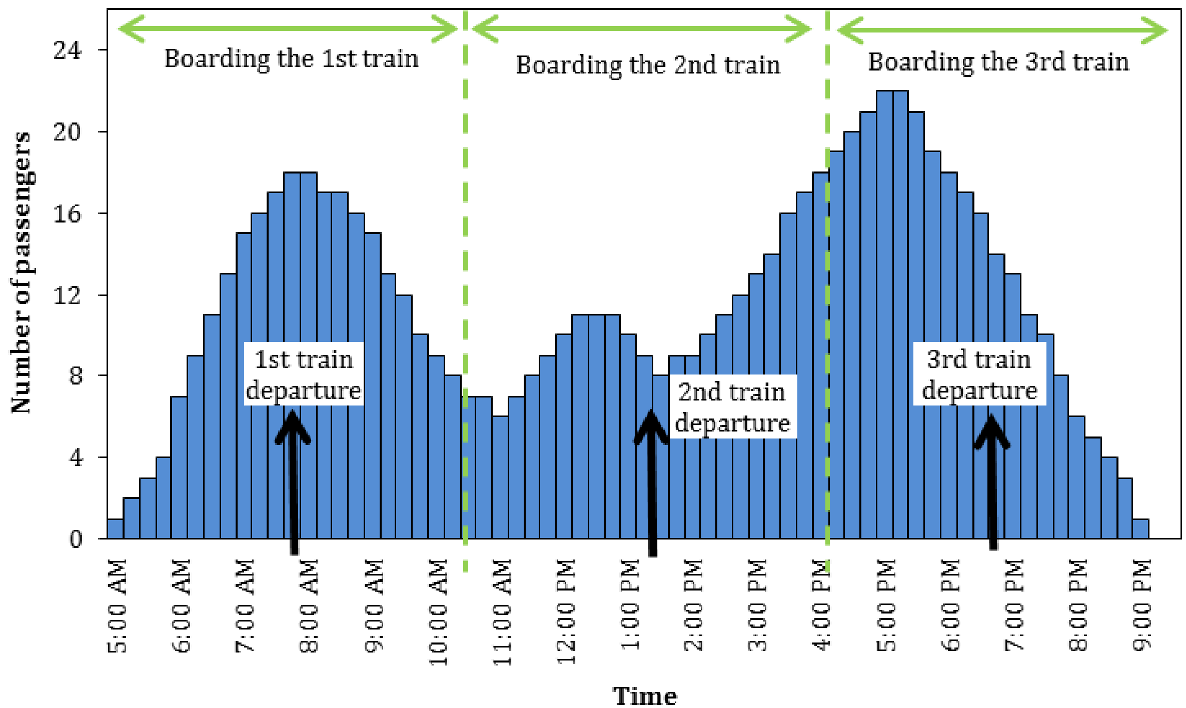


The model

Module 1: Computing passenger delay components

- Each O-D pair has a passenger demand profile (Preferred Departure Time)
- Passengers are served by a predetermined number of trains



The model

Module 1: Computing passenger delay components

- Passenger demand is elastic w.r.t. schedule delay
- Find the number of passengers departing the origin of station pair *w* at each time period *s*:

$$\boxed{q_{s_i}^{w,m}} = \boxed{q_{s_b}^{w,m}} \left(1 - \boxed{e_{d/w}} \left(1 - \frac{s_{s_i}^{w,m}}{s_b^{w,m}} \right) \right)$$

Total number of passengers leaving the origin of station pair *w* towards the destination of station pair *w* and desire to leave between $t=m$-1 and $t=m$, when schedule s_b is in place

Elasticity of demand w.r.t. schedule delay

The model

Module 1: Computing passenger delay components

- We account for passenger en-route delay in two situations:
  - When a train stops at a siding
  - While a train is conducting layover at an intermediate station

The model

Module 2: Solving the freight train scheduling problem

- Freight train scheduling is not precise and stringent in the US
- Freight trains are inserted among passenger trains (scheduling priority is granted to passenger trains)
- Minimize total freight side cost: sum of lost demand cost, train en-route delay cost, and train departure delay cost

Talebian, A., Zou, B., 2015. Train planning on a single track shared-use passenger and freight corridor with demand considerations: a focus on the US context. Submitted to Transportation Research Part B: Methodological.

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Module 3: Establishing utility and cost values

$$u_{s_i}^{P} = \boxed{TOR_{s_i}} - \boxed{TOC_{s_i}} - \left(\boxed{TSC_{s_i}} - \boxed{TSC_{s_b}}\right) - \left(\boxed{TEC_{s_i}} - \boxed{TEC_{s_b}}\right)$$

Total operating revenue for schedule s_i

Total operating cost for schedule s_i

Total schedule delay cost for schedule s_i

Passenger en-route delay cost for schedule s_i

Total schedule delay cost for the baseline schedule

Passenger en-route delay cost for the baseline schedule

The model

Module 3: Establishing utility and cost values

Lost demand cost for schedule s_i

Lost demand cost for pure freight traffic

Departure delay cost for schedule s_i

Departure delay cost for pure freight traffic

Line-haul costs for schedule s_i

Line-haul costs for pure freight traffic

$$C^F_{s_i} = \left(\boxed{LDC_{s_i}} - \boxed{LDC_{PFT}}\right) + \left(\boxed{DDC_{s_i}} - \boxed{DDC_{PFT}}\right) + \left(\boxed{LHC_{s_i}} - \boxed{LHC_{PFT}}\right) + \left(\boxed{TMC_{s_i}} - \boxed{TMC_{PFT}}\right)$$

Total maintenance costs for schedule s_i

Total maintenance costs for pure freight traffic

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The model

Negotiation stage

- A two-level, bargaining-based mode:

  Upper-level: Schedule bargaining

  A backward approach

  Lower-level: Price bargaining

  A fictitious game: takes place in players' minds

- A backward approach: first determine the price of each schedule. Then, solve for the equilibrium schedule
- We solve the game for two settings with complete and incomplete information

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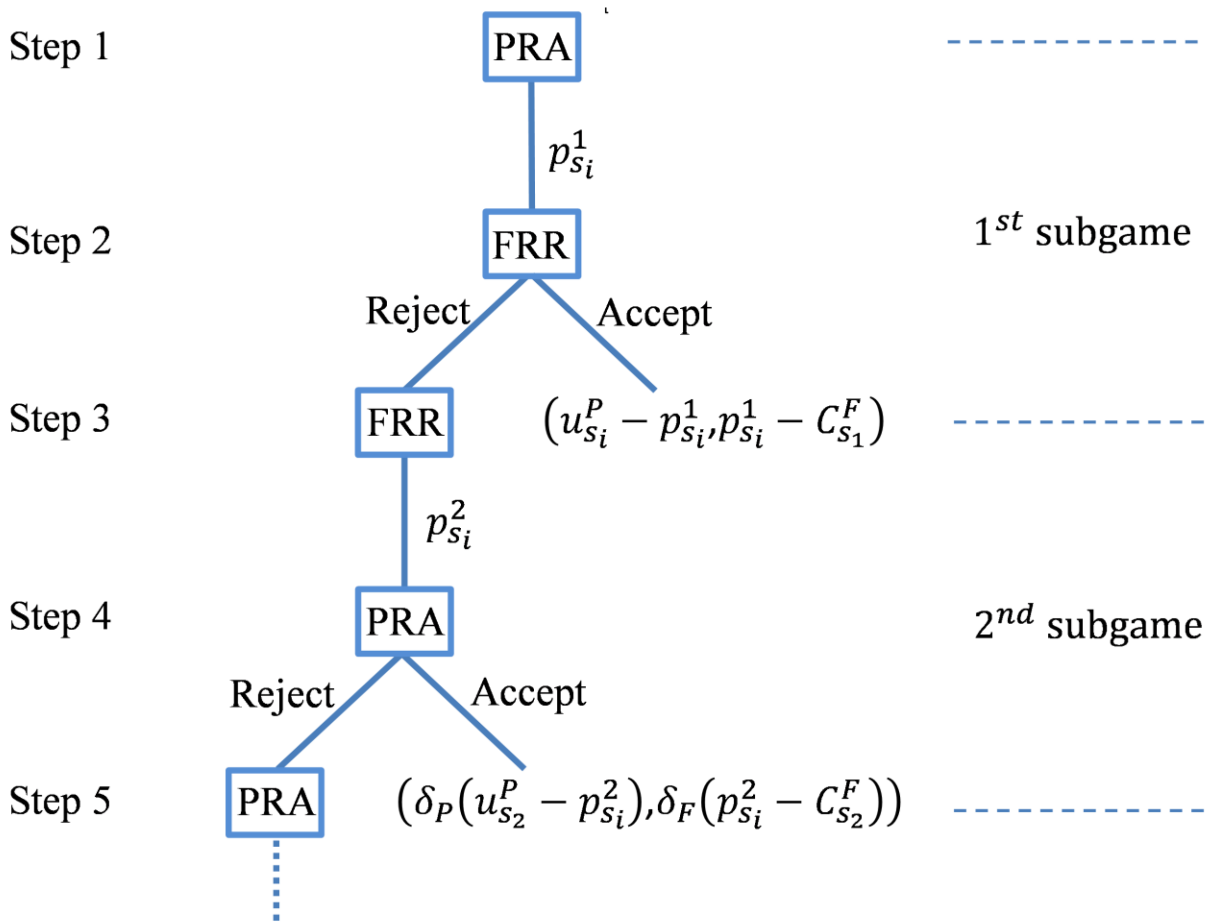
The model

Complete information price bargaining game



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$- \delta_F)C^F_{s_i})$

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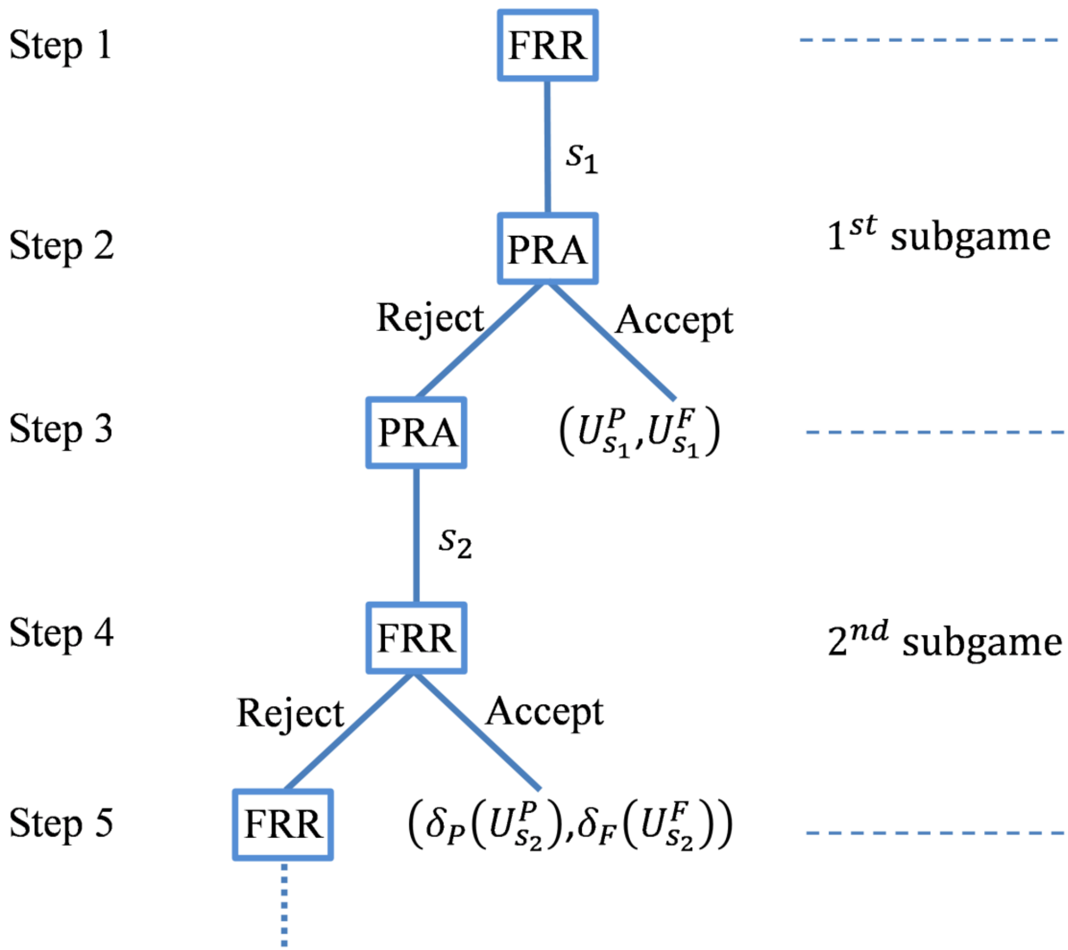
The model

Complete information schedule bargaining game



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The model

Incomplete information price bargaining game

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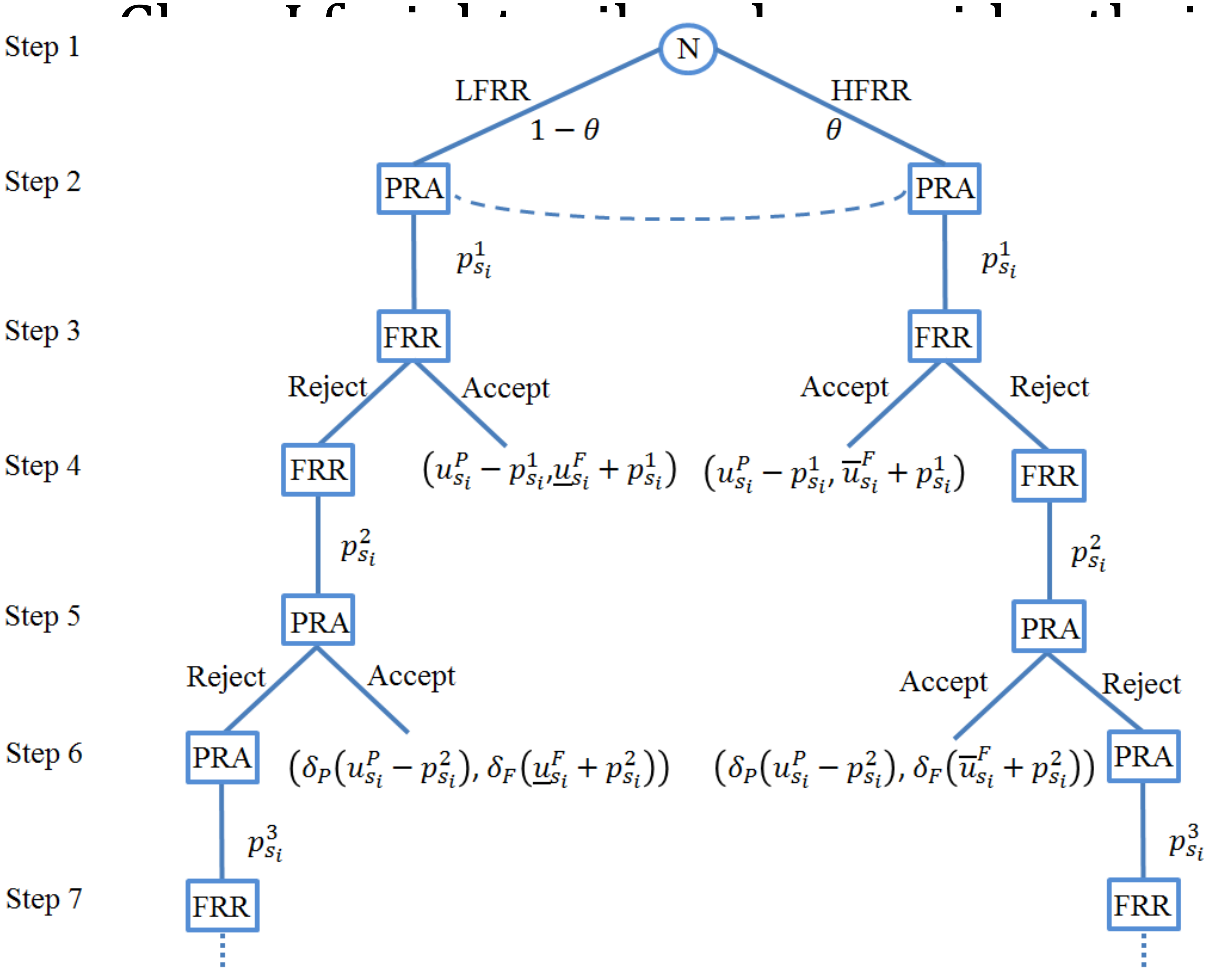

The model

Incomplete information price bargaining game

- We conjecture two equilibria for the game (only one equilibrium will occur depending on θ value)
- Equilibrium 1: PRA is highly confident that FRR is HFRR; therefore, he offers the price high enough such that HFRR accepts it
- Equilibrium 2: PRA highly believes that FRR is low-cost; therefore, he lowers the price such that only LFRR accepts the offer

The model

Incomplete information schedule bargaining game

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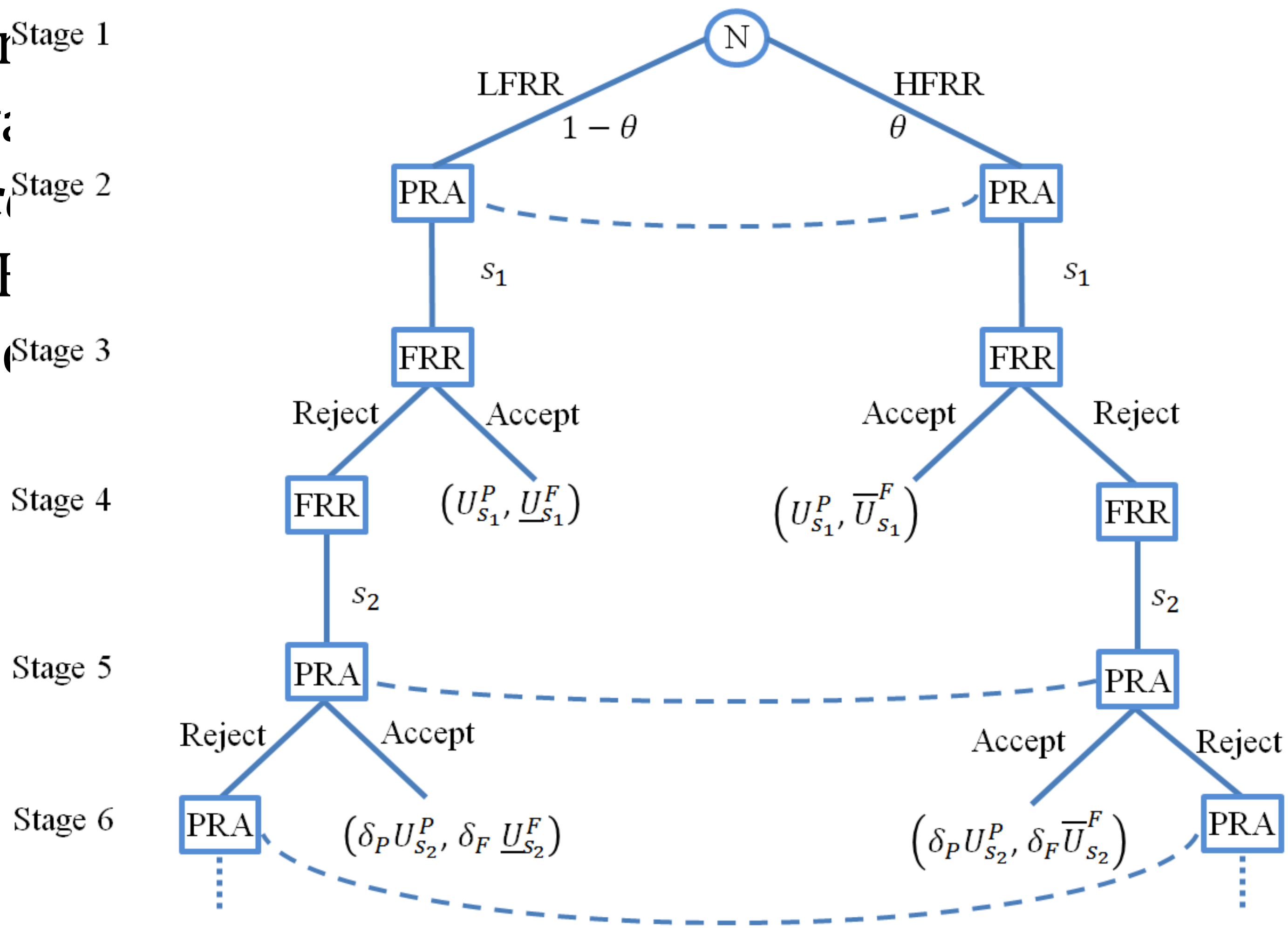

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Numerical analysis

- Set up:
  - 11 blocks: 6 track segments and 5 sidings
  - 2 O-D pairs (one in each direction)
  - Each track segment 18 miles long
  - Sidings evenly distributed along the corridor, each 2 miles long
  - Total corridor length: 120 miles
  - Planning time horizon: 5 AM to 9:30 PM (i.e., 16.5 hours), discretized into 5 minutes time periods
  - Consider daily service frequency of 1-5 trains

Numerical analysis

- Set up (cont'd)
  - Operating speed: 120 mph for passenger trains and 60 mph for freight trains
  - Elastic passenger demand (elasticity: 0.4, based on Adler et al. (2010))
  - Parameter values are obtained from the literature
  - $\delta_P = 0.9, \delta_F = 0.85$
  - Total en-route delay for each physical train is less than the pre-specified maximum en-route delay time (MED)

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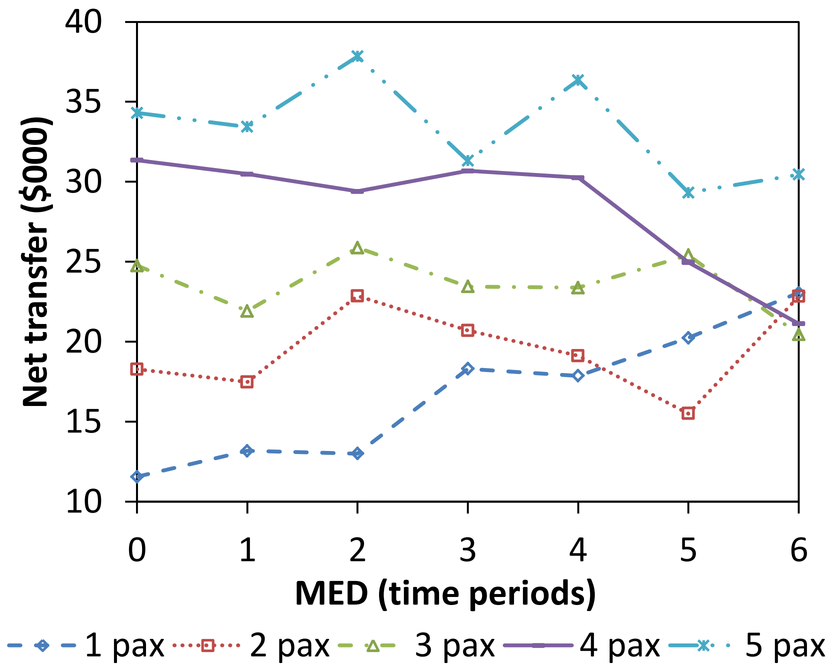
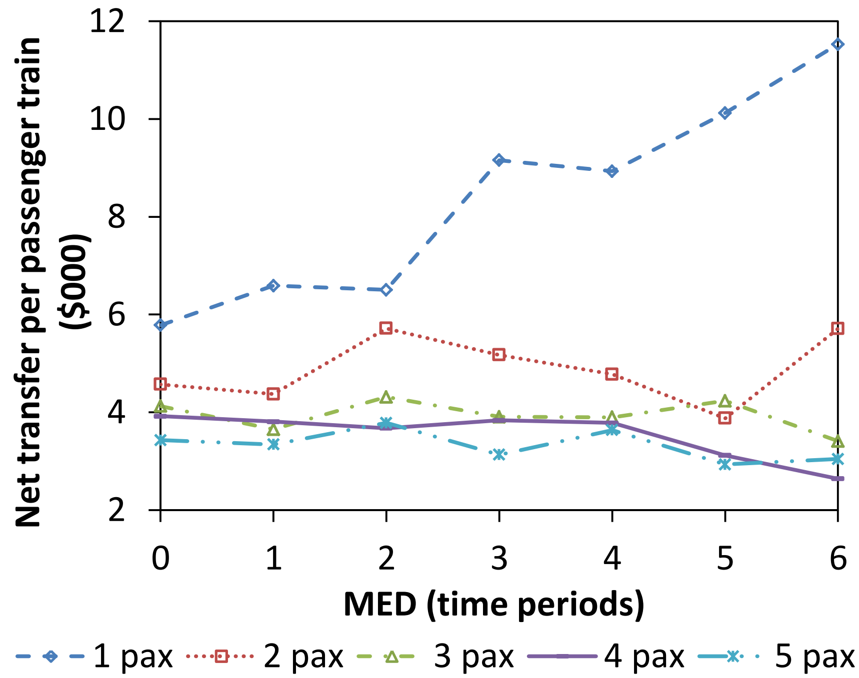
Numerical analysis

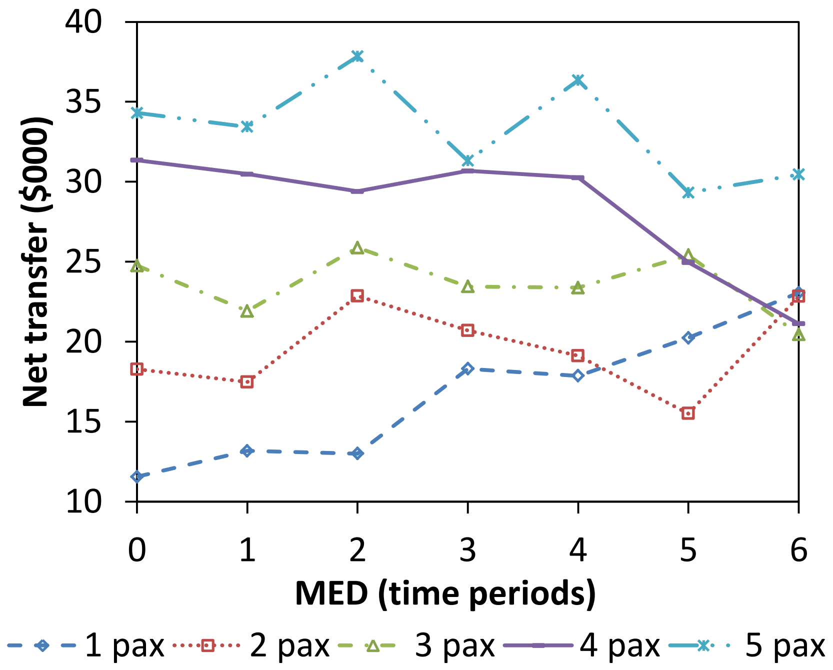
- Results
  - Increasing service frequency generally elevates the amount of net payment as it imposes additional costs to the host freight railroad

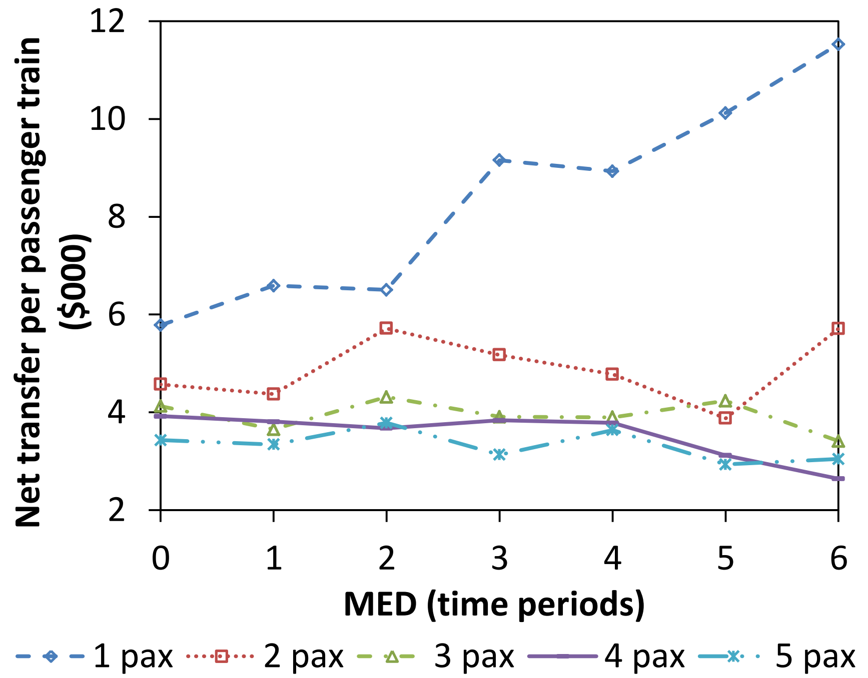




Numerical analysis

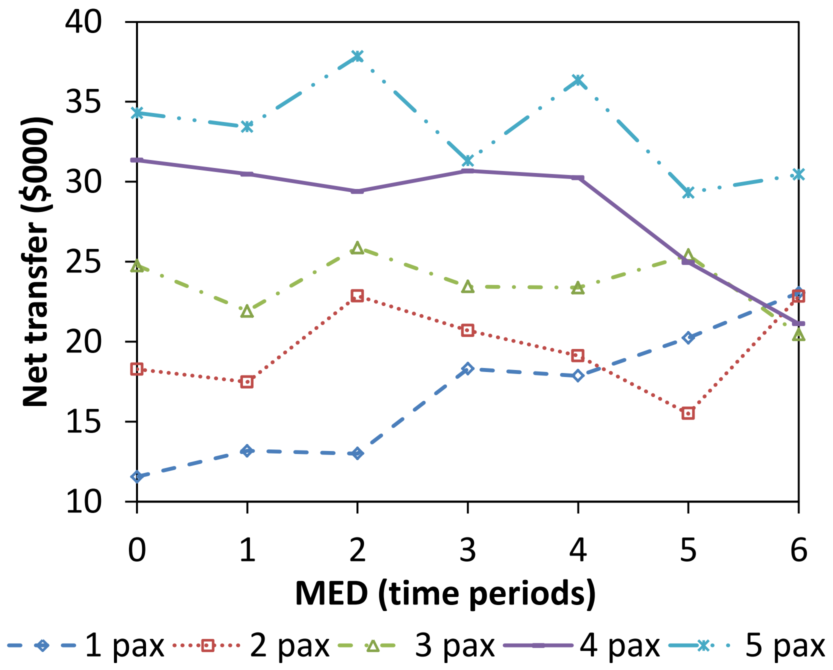
- Results
  - Elevating service frequency generally lowers the value of net transfer per train: the net payment disproportionally increases with rail service frequency

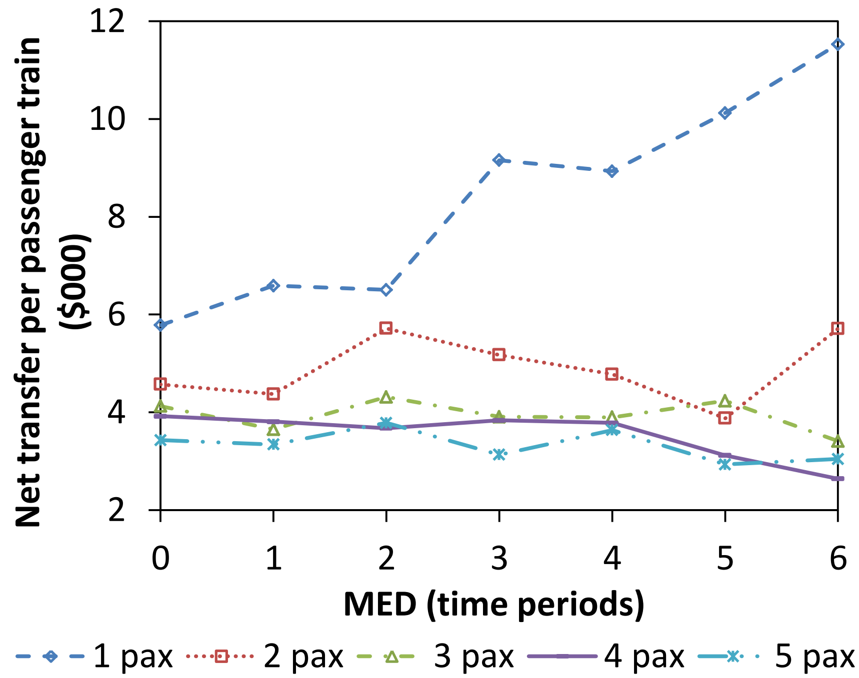




Numerical analysis

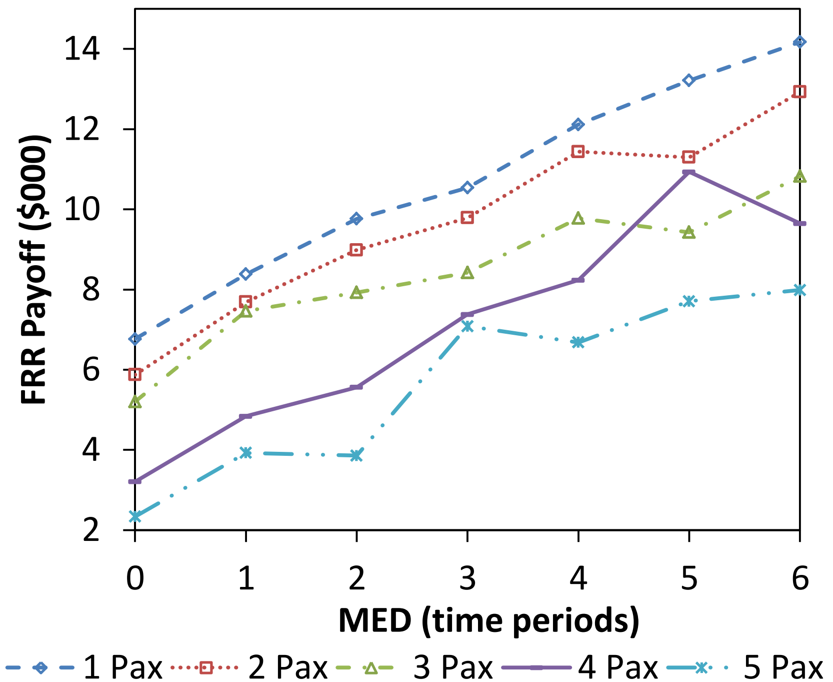
- Results
  - In 2009, Amtrak's average track usage payment is \$4.44 per train-mile, which translates to \$549 per train for the use of a 120-mile segment





Numerical analysis

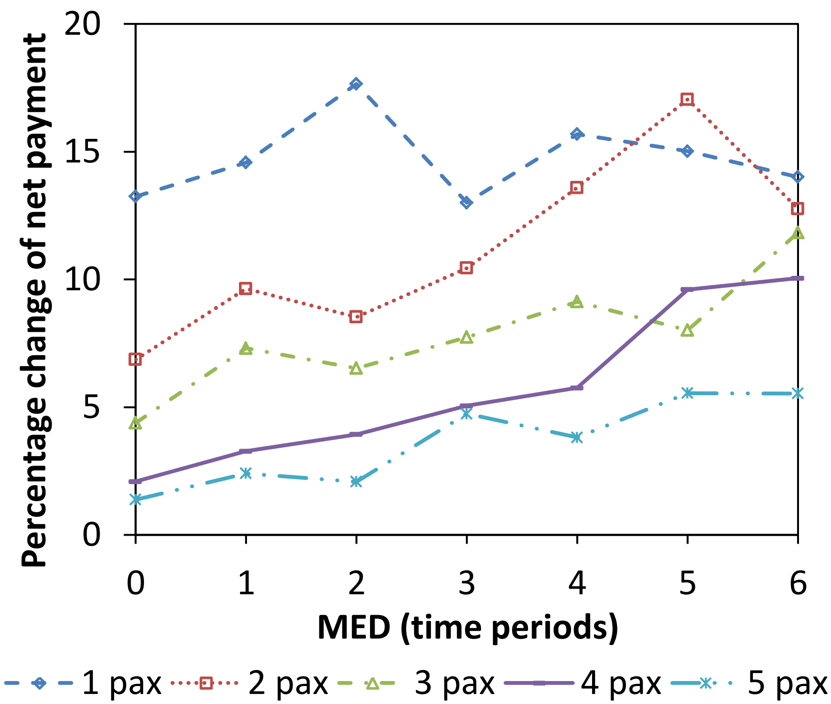
- Results
  - Given passenger service frequency, FRR's payoff generally increases with maximum en-route delay time



  - The host freight railroad prefers higher maximum en-route delays

Numerical analysis

- Results
  - The vertical axis denotes increase percentage in net transfer value due to altering the player initiating the game
  - If FRR initiates the schedule bargaining, the net payment will increase by 17.7%

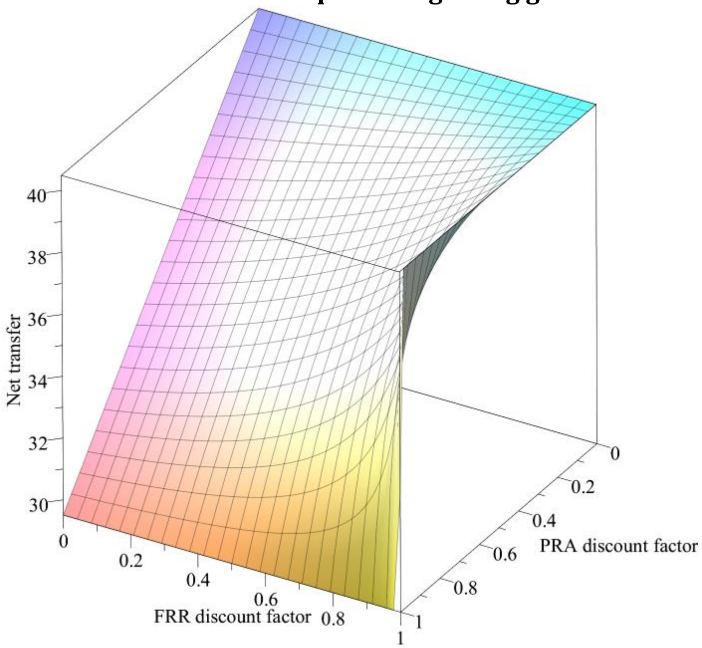


  - The impact of the initiator is amplified when we reduce passenger service frequency

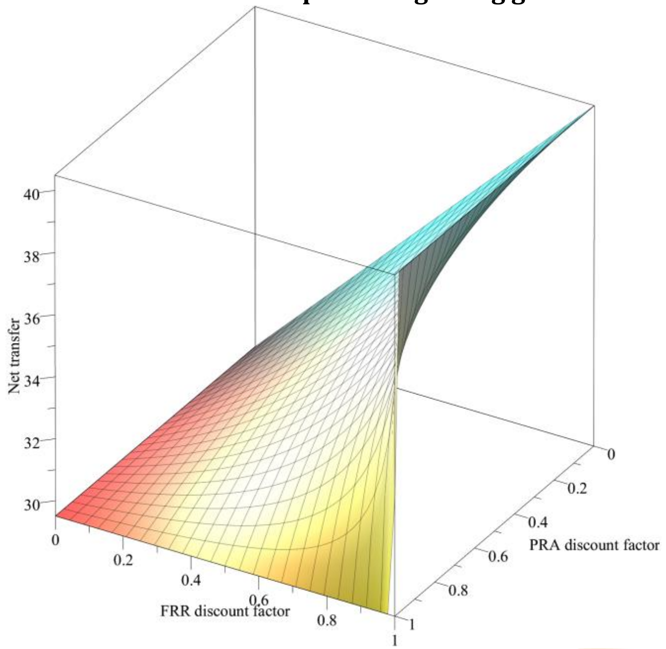
Numerical analysis

- Results
  - The net payment in each panel falls in the wide range of $30,000-40,000

FRR initiates the price bargaining game



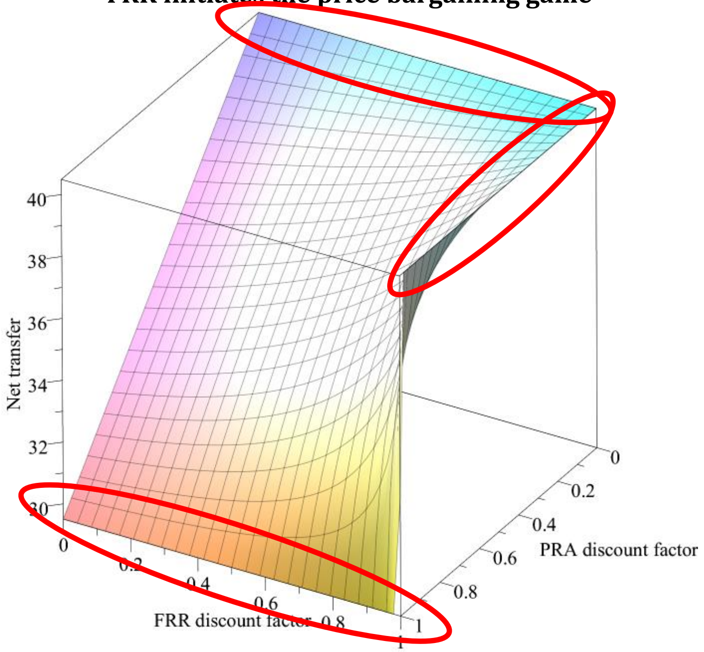
PRA initiates the price bargaining game



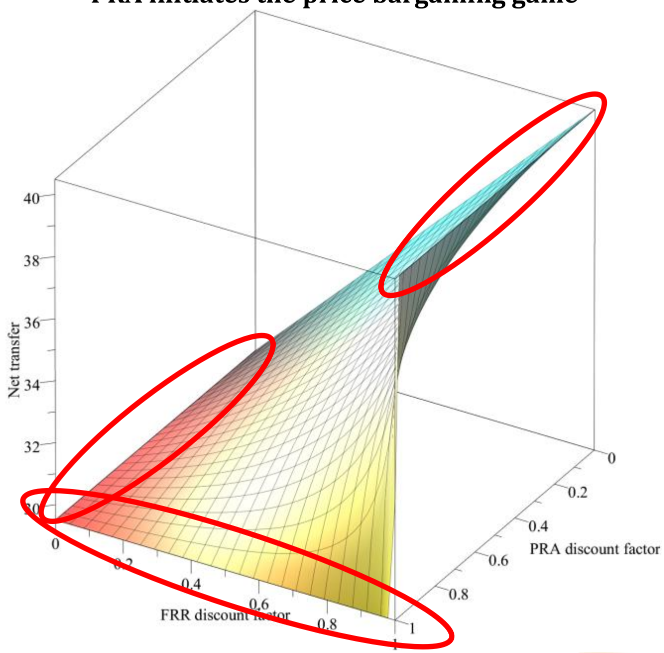
Numerical analysis

- Results
  - When one of the players is extremely patient or impatient, the problem takes on a special form

FRR initiates the price bargaining game

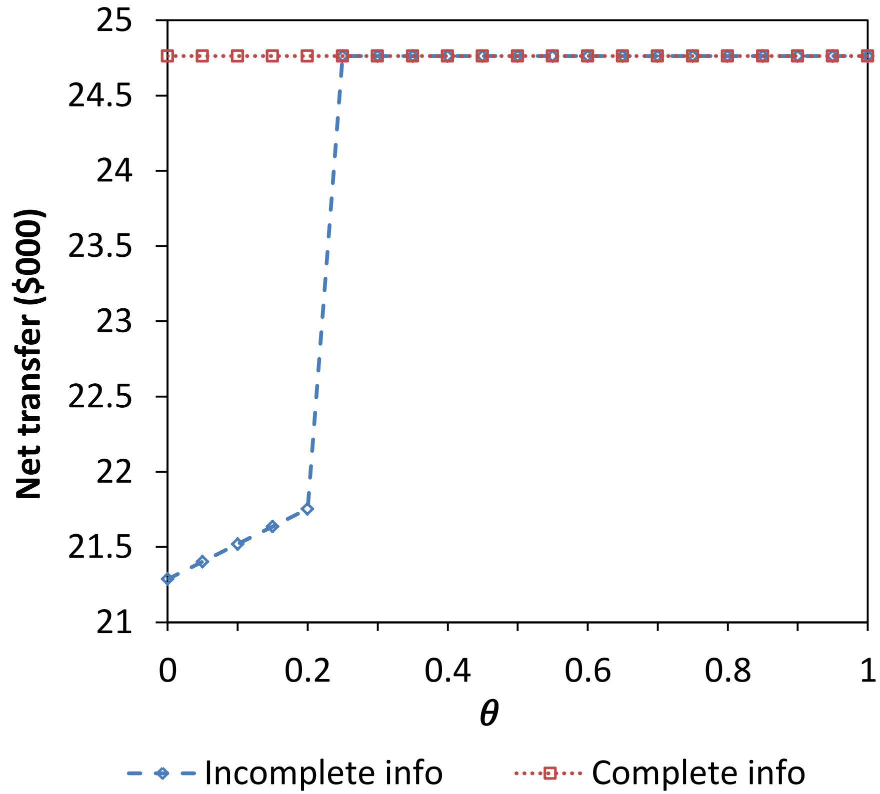


PRA initiates the price bargaining game



Numerical analysis (incomplete information)

- Results
  - Assume FRR is of high-cost type
  - We incrementally increase PRA's prior belief (θ) that FRR is of high-cost type
  - PRA makes a mistake in recognizing FRR's type. Thus FRR reduces the net payment offer to avoid delays



  - Inefficiency (due to in accurate PRA's perception of FRR's type) could lead to lower payments from PRA to FRR

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Concluding remarks

- Proposed the first sequential bargaining game model to identify capacity shares and associated charges on shared-use rail corridors in the US
- The effect of passenger train schedule on rail passenger demand is explicitly incorporated into valuation of passenger train schedules
- Two stages: pre-negotiation and negotiation
- A two level negotiation model: upper-level schedule bargaining game and lower-level price bargaining game

Concluding remarks

- Negotiation: complete and incomplete information settings
- The game of complete information is analytically solved. Efficient passenger train schedule is the one maximizing the utility of passenger rail agency minus freight side cost
- The equilibrium schedule is independent of discount factors, as well as who initiates the bargaining

Concluding remarks

- Bargaining with incomplete information: the freight railroad keeps its cost values confidential
- Using realistic parameter values, applicability of the models is demonstrated on a single track shared-use corridor
- Net payment significantly increases with passenger train frequency. However, the rate of increase is less than proportional

Policy insights

- The payment from Amtrak to the freight railroads seems lower than it should be (given that Amtrak receives true scheduling priority)
- The freight railroad prefers Amtrak trains to have higher en-route delays (in the planning stage)
- Who initiating the bargaining makes a difference to net payment, but not the equilibrium schedule
- Discounting factor (the impact of delayed agreement) critically determines the net payment

Thank you!

Questions and comments

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